VERNE: Revealing the Histories and Mysteries of Venus

A proposed New Frontiers mission to Venus formulated as part of JPL's Planetary Science Summer School

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Science Objectives

Objective 1: What is the composition of the Venusian unknown UV absorber?

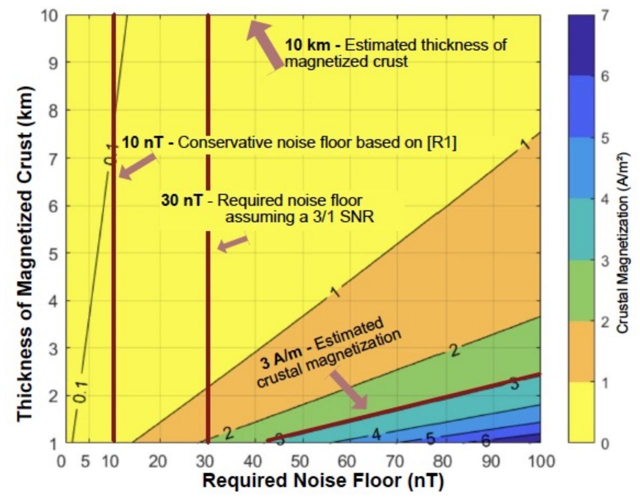
- **Background:** UV absorption directs energy deposition and drives Venus' global atmospheric circulation
  - First observed in upper cloud deck ~100 years ago [1]
  - Unknown absorber + CO_2 is an absorption sink for ~50% of the solar flux received by the planet [2]
- **Candidate UV Absorbers:**
  - Sulfur bearing species (SO_2, OSSO, SO, aerosols) [3,4,5]
  - Iron Chloride ($FeCl_3$) aerosol [6]
- **Scientific Goal:** understand the role of atmospheric sulfur chemistry in climate on an Earth-like planet
  - Aid climate models by showing how and where incident solar energy is absorbed by the atmosphere

Objective 2: Does Venus have remanent crustal magnetism preserved in the Tessera terrain?

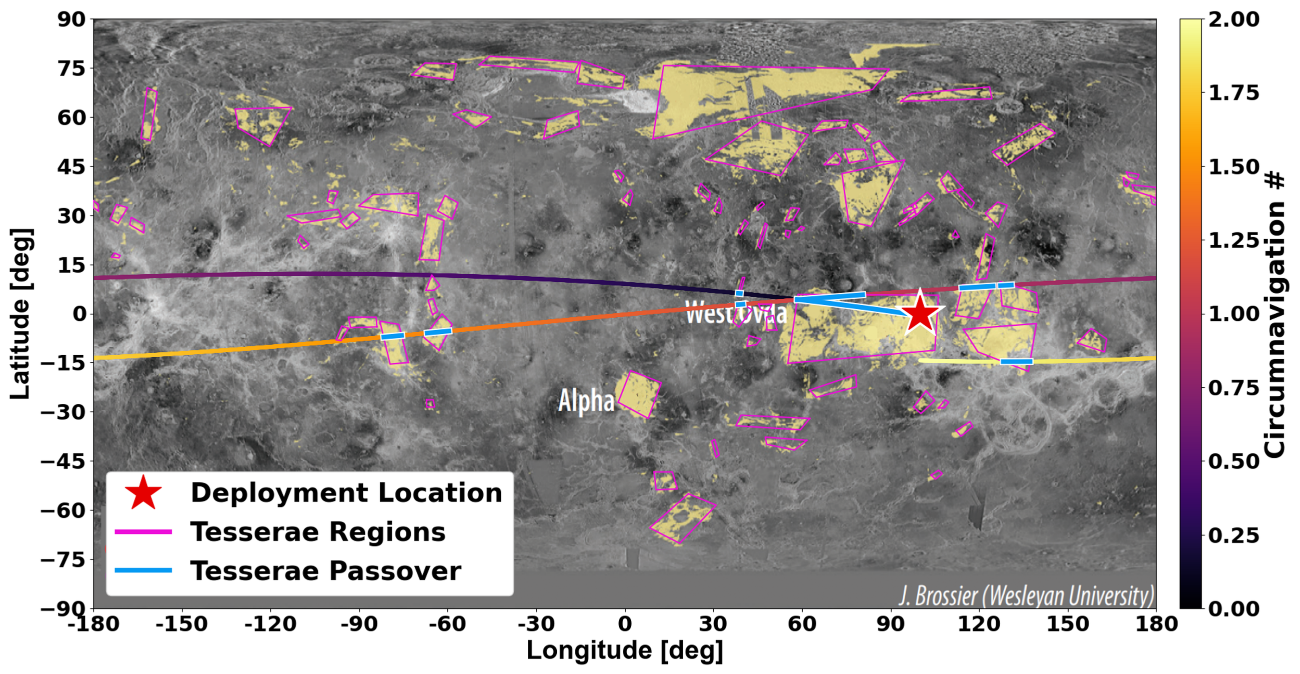
- **Background:** Venus currently lacks a global, internally-generated magnetic field
  - Lack of internally-generated magnetic field impacts evolution of the atmosphere (e.g., atmospheric loss rates)
  - Distribution of magnetization can shed light on Venus' core dynamo and past tectonic regimes (e.g., mobile lid tectonics)
- **Remanent Crustal Magnetization (RCM):**
  - Tesserae regions are the oldest geological units on Venus' surface and most likely regions to preserve RCM signatures
  - Mapping the RCM on Venus may capture past motion of crust and constrain lithospheric evolution of Venus
- **Scientific Goal:** understand how planetary magnetic fields are initiated and maintained
  - Evidence as to whether Venus used to be Earth-like and why the planet has the hostile environment that exists today

Mission Requirements

- **UV Absorber Requirements**
  - Measurements of abundance and spatio-temporal distribution of sulfur and organic species + size distribution of aerosols
  - Altitude between 60 and 75 km
  - Time interval of at least 2 hours (cloud top SO_2 has variation) [7,8] with temporal resolution of <12 minutes (UV absorber variation) [9]
- **RCM Requirements**
  - Instrument requirements account for expected magnetization of rock, size of surface features, sampling rate to mitigate confounding effects of ionosphere, spatial coverage of features, and altitude of platform



  - Sampling frequency of 10 Hz is based on confounding ionospheric signal fluctuations (~1 Hz) [10], speed of platform (<150 m/s) [11], and expected size of magnetized features (100 km) [12]
- **Circumnavigation Requirements**
  - RCM objective requires measurement over 2+ tesserae regions
    - Used Monte Carlo simulations of balloon path estimates [13] and determined that 2 circumnavigations are required to observe 2+ tesserae regions with 99% confidence



Mission Overview

- **VERNE**: **V**enus **E**nvironment **R**esearch and **N**ovel **E**xploration
- 9 days of in-situ data collection within upper cloud deck (62 km)
- 3-part flight system: in-situ balloon and gondola, entry system, and orbiter for data relay
- 3300 kg (wet w/ contingency)
- PI-managed cost estimate (NICM & JPL ICM): $894.4M

Mission Implementation

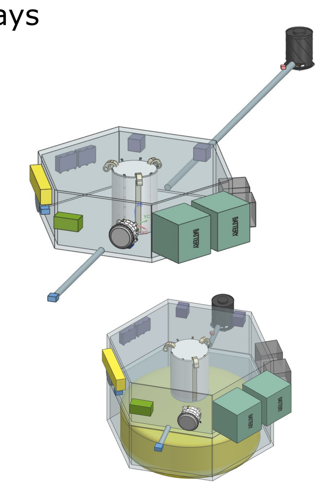
- **Flight System**
  - *Entry System* – aeroshell and parachute scaled based on similar designs from previously flown missions
  - *Cruise Stage / Orbiter (CSO)* – most subsystems scaled based on previous missions except ADCS and propulsion system
  - *Aerial Platform* – mechanical & configuration, ADCS, thermal, command & data handling, telecommunications, power, and flight software designed to meet VERNE's mission requirements

	MEV* (kg)
Launch Mass	**3300.3**
Aerial Platform	980
Aeroshell	683
CSO	1593
Launch Vehicle Capability	3500
Launch Vehicle Margin	**199.7**

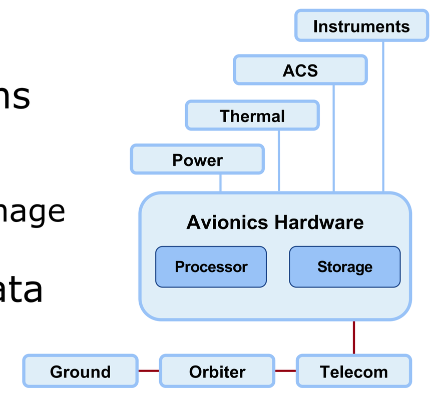
*MEV includes 43% total contingency

- **Launch Date:** June 7, 2032
- **C3:** 8.77 km^2/s^2
- **Intermediate-High Performance Class launch vehicle with 4-m fairing**
- **Mission Duration:** 475 days
  - Cruise: 454 days
  - Coast: 5 days
  - Orbit initialization: 7 days
  - Science phase: 9 days
- **ΔV:** 1145 m/s

- **Mechanical and Configuration**
  - Bottom chassis contains inflation system (helium tank jettisoned after inflation)
  - Top chassis (gondola) contains packed balloon and two booms deployed after inflation for science and communication instruments
    - Antenna and UV camera on 2.7-m boom, magnetometer on 1-m boom

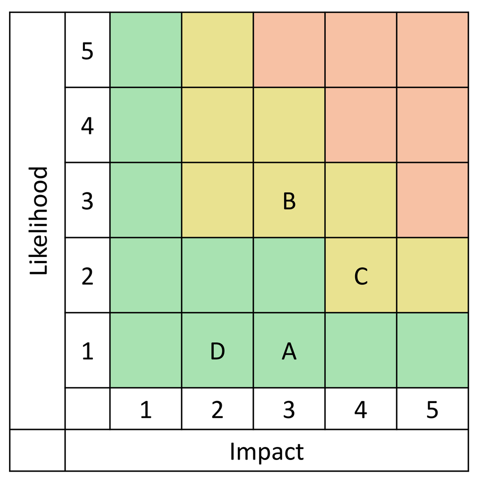


- **ADCS**
  - Orbiter pointing requirements driven by telecommunications mode
  - Orbiter is spin stabilized except for telecom mode (3-axis stabilized)
  - Gondola pointing requirements driven by the UV (X/Y) and RCM (Z) science objectives
  - Aerial platform is not actively controlled
- **Thermal**
  - Passive thermal control sized based on 62 km altitude, corresponding to temperature of -20°C and gust speeds of 1.5 m/s
    - Cooling – small radiator on gondola surface coated in silverized Teflon
    - Heating – gondola surface coated with insulating Solimide foam to maintain minimum operating temperatures of -20°C
- **Command and Data Handling**
  - Sphinx – designed at JPL for deep space missions
    - Radiation hardness and single event fault tolerance exceed Venus mission requirements
    - Single card for avionics, data storage, and simple image processing results in low mass and power draw
  - 64 Gb memory significantly exceeds required data storage of 40.4 Mb
  - SpaceWire interfaces handle housekeeping and science data



- **Telecommunications**
  - Data flows from the aerial platform to the CSO to Earth
    - Balloon-to-CSO communication uses S-band with required data rate of 9 kbps
  - DSN used for ranging as long as Earth-to-Venus distance is <0.8 AU
- **Power**
  - Aerial platform powered with 590 Li-SOCl2 primary battery cells
  - 15.6 kWh energy requirement → margined requirement of 24.6 kWh

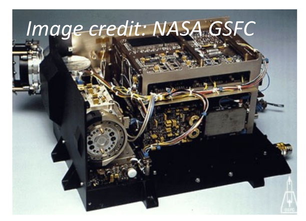
Risk Assessment



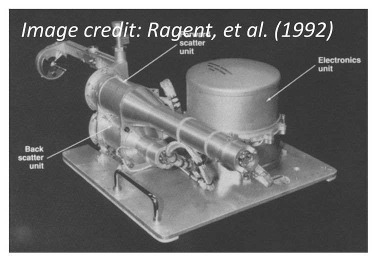
Risk	Examples	Mitigation Strategy
A. Balloon operations	Failure to endure Venusian environment, operation below required altitude	JPL's ongoing funded balloon development plan (includes flying balloon prototypes)
B. Balloon deployment	Inflation system failure, failure in jettisoning balloon from gondola	Phase A extension; allocation of additional $20M for inflation system development
C. Power	Growth in power requirements leading to rapid increase in mass	Trade study to assess solar power during Phase A; consider descoping nephelometer
D. Sphinx	Sphinx system not reaching TRL 9 by time of launch	Expected to fly on multiple upcoming missions

Instruments

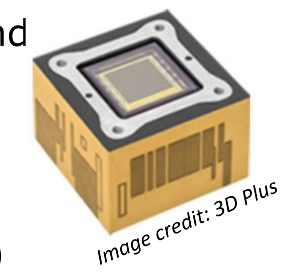
- **Adams (INMS):** detect and distinguish mixing ratios of various sulfur and organic species
  - Spatial (longitudinal) and temporal (day/night) variations observations
  - Sample cadence: 12 minutes
  - Analogue instrument: Cassini INMS
  - Modifications: larger ranger and higher resolution



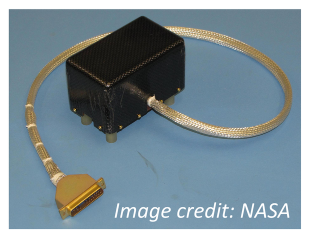
- **Shelley (Nephelometer):** determine size distribution of aerosols in Venusian atmosphere
  - Same sampling cadence as INMS
  - Range of 0.4 to 36 μm
  - Size resolution of <0.7 μm
  - Analogue instrument: Galileo nephelometer

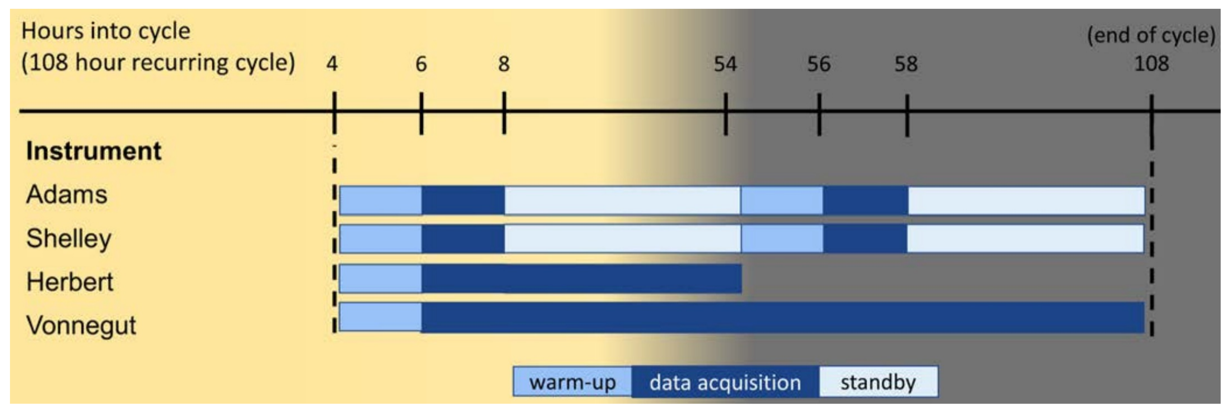


- **Herbert (UV Imager):** measure UV radiance at 283 nm (wavelength of SO2 absorption) and 365 nm (wavelength of unknown UV absorber)
  - Measurements taken concurrently with INMS and nephelometer to correlate UV absorption with observed species
  - Analogue instrument: 3D+ camera
  - Modifications: validate camera down to 283 nm (currently validated between 300 and 1000 nm)



- **Vonnegut (Magnetometer):** measure magnetic field signatures emanating from the surface
  - Measurements taken throughout science phase of mission
  - Analogue instrument: MAVEN fluxgate magnetometer





Lessons Learned

- **Planetary Protection**
  - Venus missions are Planetary Protection Category II (risk of spacecraft-borne contamination compromising investigations is low)
  - Current debate about existence of life in Venus' clouds
  - Searching for life would require increased sterilization, adding significant cost to the mission
- **VISE Requirements**
  - Originally designed to help achieve science quickly, but has become systemic barrier to advancing Venus science
  - Requirement to meet a preponderance of objectives may be too stringent
    - Simultaneously addressing 4 objectives requires too many resources and is unlikely to be achieved with the current cost cap

References and Acknowledgements

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